ANALYSIS OF A DESCRIPTIVE MODEL FOR HAND MOTION DISTANCE IN A MANUAL DECISION TASK

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THESIS

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Analysis of a Descriptive Model
for Hand Motion Distance in a Manual Decision Task

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ABSTRACT

An experimental investigation was conducted to examine a descriptive model for hand motion under discrete uncertainty of the stimulus set. The design and implementation of an automatic, on-line, data collection device using cyclegraphic motion collection methods is described. Eight subjects were exposed to 2.2 to 3 bits of choice uncertainty. Response times, error rates, and hand motion distances were collected and analyzed. Hand motion distances were compared to straight line distances used in control panel design. Further investigation indicated that the distributions of hand motion distances, for any stimulus, fit normal curves, and that variations in subject performance were significant. Perceptual aspects of the task and operator strategies are discussed. Further study is suggested.

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I. RESEARCH OBJECTIVES

In recent years a number of researchers have studied human responses to imposed stimuli. Efforts were directed toward understanding human operator response parameters, and toward development of accurate relationships between measures of human performance and the stimulus set, work task, or work environment being considered. This paper is directed toward the investigation of one of those proposed relationships concerning hand motion distance.

A precursor to the investigation was the design of laboratory equipment sufficient to allow rapid, automatic data collection. Designs offered in other works, while sufficient for those tasks, were not general in nature. A secondary objective then was the design of modern equipment, using recent technology and the data collection facilities of an on-line digital computer. That design is treated extensively in the appendices.

A. BACKGROUND

Industries and the military services are adopting the computer as the central component in systems which are designed for machinery control and information display. In tasks which require a decision, information is processed by the machine and presented to the man at a control panel. The operator's decision processes using the data require time delays that are much greater than modern computer processing times. In time critical tasks, any delay is usually undesirable. Poor panel design at the interface can add to response time and increase errors in transfer of information between man and machine (Wargo, 1967).

Proposed models which relate stimuli and physical dimensions to modes of action have been considered by a number of researchers, however none have proved entirely sufficient to date. Consequently designers of control panels are presently without adequate descriptive models for hand motion. Early investigators in industry were interested in the improvement of work efficiency and work methods. Frederick W. Taylor is widely recognized for his work in time study and the redesign of manual work equipments. His methods predated those of industrial engineers. Micromotion study was created by Frank and Lillian Gilbreth who were interested in motion economy. Their early work with photography resulted in the cyclegraph and chronocyclegraph. Applications of the cyclegraphic technique were used in this study (see Appendix B). The works of Taylor and the Gilbreths laid the foundation for many motion prediction methods that have been accepted by industry (Barnes, 1968).

More recent efforts have been directed toward measuring human information handling capacity and response ranges. Rubin, et. al. (1952), investigated motion paths over a control surface and found that the response motion was comprised of a travel component and a manipulative component. Learning appeared to occur in the manipulative component alone. They concluded that motion complexity had very little to do with times associated with the two components. Simon and Smader (1955) examined a decision task wherein a forced visual discrimination occurred during a complex hand motion. They reported that the necessity to discriminate between stimuli changed motion times. They also noted that industrial motion prediction methods did not address that phenomenon.

Early attempts to quantify the relationship between response times and discrimination between discrete alternatives were reported by Hick

and by Hyman. They conducted laboratory experiments that consisted of subjects responding to randomly occurring lights (stimuli) by pressing appropriate buttons (Welford, 1968). Their results indicated a linear relationship between response time and the uncertainty of the stimuli as quantified by Shannon's so-called information metric.

$$H_p = \sum_{i=1}^{n} p_i \, \mathrm{Log}_2 \, (1/p_i) \qquad (1)$$

where p_i is the probability that stimulus i (i=1,...,L) occurs.

Other investigators such as Fitts and Peterson (1964), Mowbray and Rhoades (1959), Hilgendorf (1966), Whitefield (1966), Bernstein, et. al. (1967), and Remington (1971) extended the overall understanding of the relationship between subject response and the uncertainty in stimuli over a wide range of laboratory conditions. These are reviewed in Welford (1968).

In 1970 Kuttan and Robinson supported much of the earlier work while showing that first order models were appropriate but imperfect descriptors of response hand motion. The relationships borne out involved the models of Fitts and Peterson and the early work of Hick. Further evidence of task dependencies was offered by Redelman (1970) and by Scholes (1970), who tied motion time and response time to direction of the response as well.

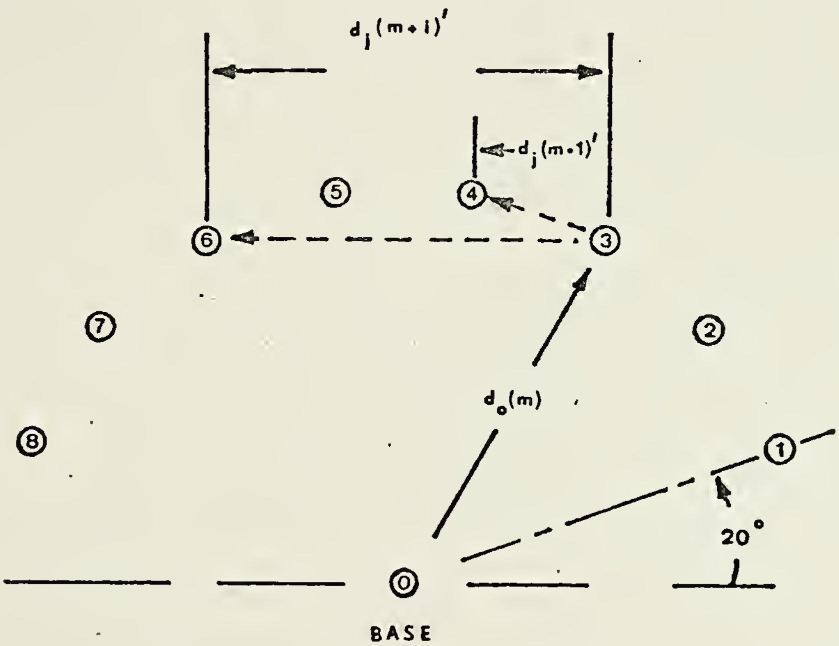
Most recently Thomas, et. al. (1973) offered a model for hand motion in the manual - decision task. The descriptive equation, presented in Section II, addresses hand motion distance associated with discrete uncertainty in the stimulus set. The results of an experimental investigation of that model, by methods outlined in Section III, are presented in Section IV. Discussion and conclusions in Section V are

augmented by a proposal for further investigation using the equipment which is now available.

II. THE DESCRIPTIVE MODEL

Most current practices in equipment design and many investigations of response phenomenon assume that the operator's hand motion, in response to a cue, traces a direct path. The path is between a terminal position of the preceding motion (Base) and the latest response control.

The proposed model, on the other hand, deals with the subject's perception of the stimulus set. It is postulated that in response to stimuli whose probability of occurrence are not uniform, the subject will perceive a most likely response control m and, through learning, will engage in motions of the hand over a distance $d_j(m) = d_o(m) = d_j(m)'$ where $d_o(m)$ is the direct distance from the terminal point of a preceeding motion to a position above the perceived most likely response



$$d_j(m) = d_o(m) + d_j(m)'$$

Proposed Path Method

FIGURE 1. HAND MOTION DIAGRAM

and, $d_j(m)'$ is the measured distance from that point to response control $j = 1,\ldots,L$.

An illustration of these component vectors is shown in Figure 1. The method used in the investigation of this model is described in the following section.

III. THE LABORATORY EXPERIMENT

A. THE TASK

The manual - decision task was presented through use of a fan shaped button board which is shown in Figure 3 and described in Appendix A. The button numbering system ran counterclockwise from the lower right position which increased the psychological difficulty of the task by opposing circular display convention. The stimuli were presented visually one at a time when the subject initiated each cycle. No appreciable time delay occurred between initiation of a cycle and stimulus appearance. The required response consisted of a reach to the button which corresponded in number to the stimulus.

Eight integers (1,...,8) were selected as the stimulus set. Shannon's information measure was used to determine the uncertainty associated with a particular proposed mix of the proportions of the eight integers on a tape. The methods given in the computer programs section of this paper were used in producing four tapes of 500 integers, each followed by a zero. The zero display was used as a feedback item to indicate cycle completion and was considered to convey no information relative to the decision task. The task was simulated during tape production to provide theoretical motion distances. These were compared in Section V with experimentally derived data evoked by the identical character string.

TABLE I. ENTROPY OF THE STIMULUS SETS

TAPE	STIMULUS PROBABILITIES (p_i) 1	2	3	4	5	6	7	8	H(p)
Practice Session 1	.125,	.125,	.125,	.125,	.125,	.125,	.125,	.125	3
Practice Session 2	.03,	.20,	.03,	.20,	.07,	.30,	.10,	.07	2.622
Practice Session 3	.072,	.072,	.500,	.072,	.072,	.072,	.072,	.072	2.402
Data Session	.05,	.50,	.05,	.05,	.05,	.05,	.20,	.05	2.261

Table I gives the probabilities for each tape which was administered to all subjects. The sequence was based on diminishing entropy for each successive session. The sessions were self paced and no communication was necessary between experimenter and subject.

B. THE SUBJECTS

The subjects were six male and two female volunteers all of which were right handed and ranged in age from 26 to 34 years. All were in good health and had no physical disabilities. These subjects were tested during four sessions which were spaced an average of 3.5 days apart. Three practice sessions preceeded the data session. Their purpose was to provide subject training and familiarization on the equipment.

C. THE EQUIPMENT

The laboratory equipment design stressed the on-line use of a modern digital computer, and advanced technology circuit elements. The block diagram in Figure 2 represents component relationships. A control panel was simulated through use of a button board arrangement

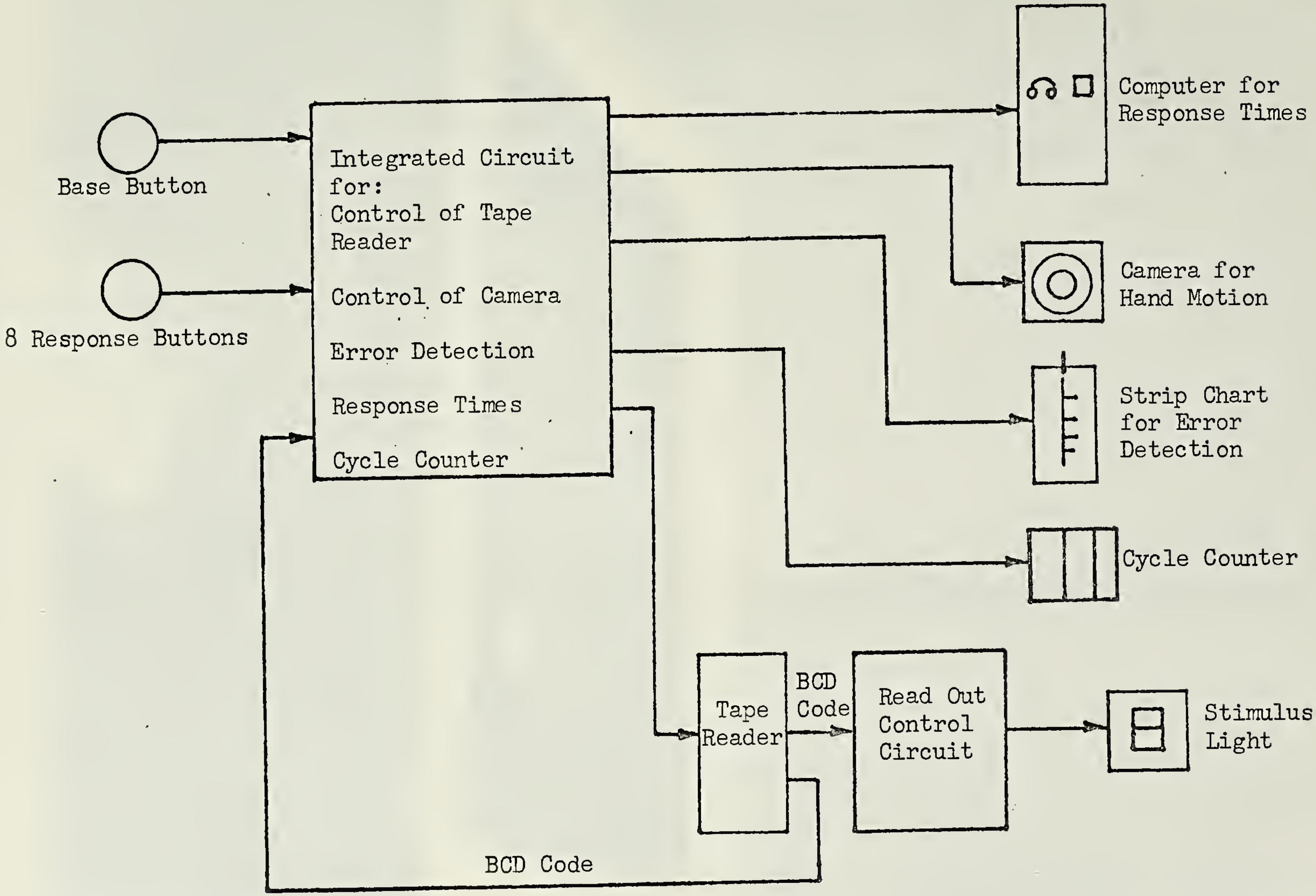


FIGURE 2. SYSTEM BLOCK DIAGRAM

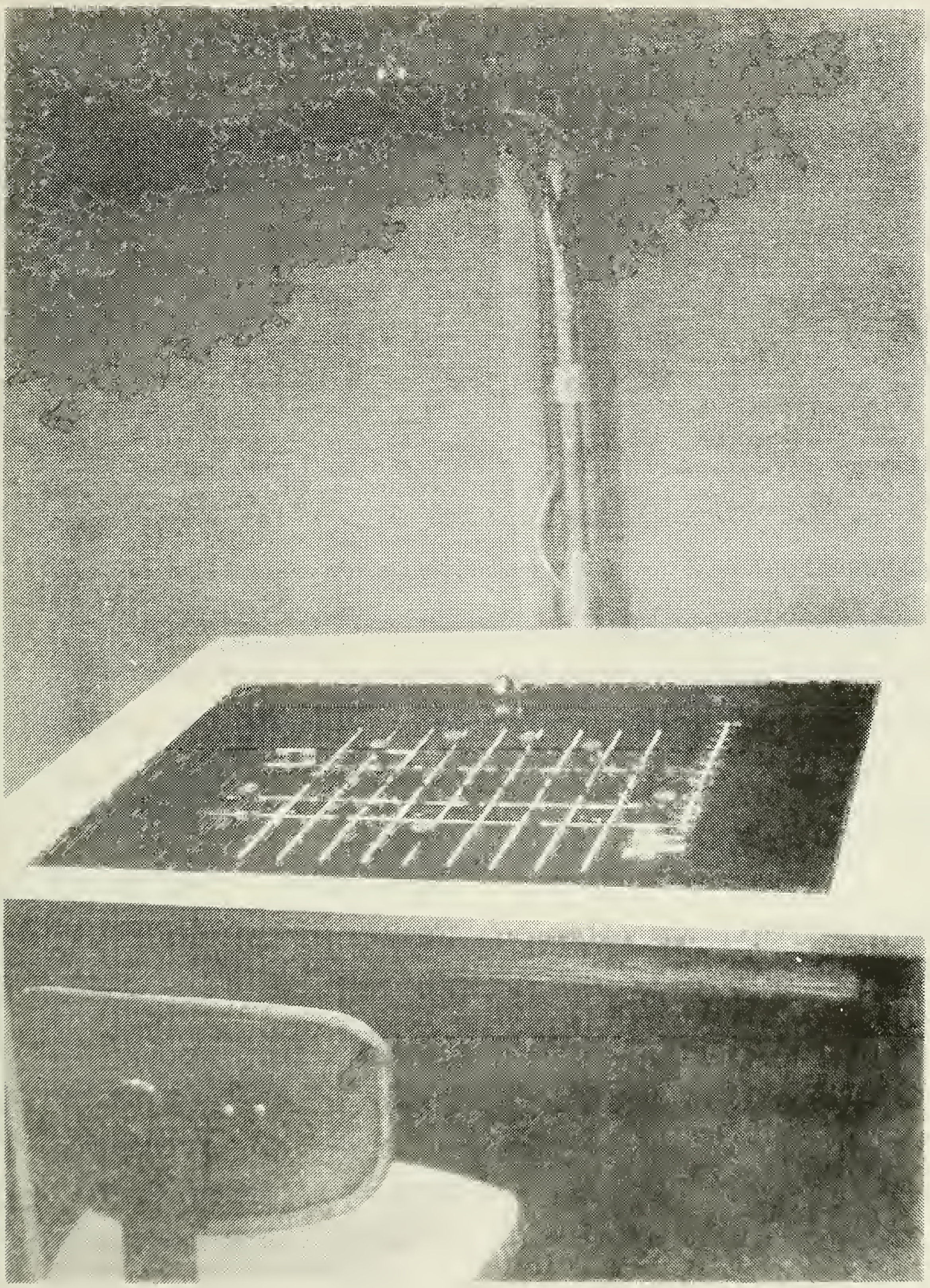


FIGURE 3. BUTTON PANEL LAYOUT

and a digital read-out as shown in Figure 3. The panel was placed in an acoustical isolation chamber which also held camera apparatus. The chamber incorporated a two-way mirror which allowed continual observation of the subject during the data sessions. A control bench positioned outside the window contained tape reader, camera control, cycle counter, Brush recorder, and intercom. The sessions proceeded automatically after initiation, which allowed the experimenter freedom to observe subjects and to monitor recording equipment.

D. PROCEDURE

At the beginning of each session subjects were carefully instructed concerning the object of the test which was to minimize the response time per cycle while minimizing errors. Correct hand positioning was stressed prior to the start of each session and the button numbering system was reviewed. The seated operator, in executing the task, engaged in hand motions which ranged from the near-high position at the base button to the far-high at response buttons 4 and 5. (Morgan, 1963). Hand motions were ballistic in nature, and control manipulation was negligible. (Barnes, 1968).

The sessions were completed in 20 to 30 minutes. Immediately upon exiting the chamber, the subjects were asked to complete a questionnaire regarding their level of fatigue, a self determination of their performance during the session, and an estimate of the contents of the stimulus set. The results are examined in Section V.A. The experimental design offered the opportunity for collection of 16,000 triads of data containing response time, hand motion distance, and correct response measures. Complete sets of response time data were collected, however, economic considerations forced a reduction in the collection

of hand motion data. One 36 exposure roll of film was exposed on each subject during each of the first and fourth sessions. The exposures during the first session were taken in groups of nine frames from four different segments of the 500 cycle sessions. These frames were used as specimens of early performance. The operation served to familiarize the subjects with the camera.

IV. DATA ANALYSIS

A. OBSERVED TENDENCIES AND SUBJECTIVE RESULTS

In conducting the experiment three preliminary considerations were important. It was first necessary to examine the effects of error and fatigue for their impact on the data base. Responses to the questionnaire were collected after each session which provided subjective indicators of fatigue and perceptual aspects of the stimulus set for the task. Tiredness in the limbs was considered absent in more than 50 percent of the responses and, when present, it was judged to be of no consequence. The overall task was considered tiring less than half the time, and 44 percent of the respondents claimed to be refreshed on task completion. Observations of subjects during data collection sessions indicated increases in the length of rest periods, repeated flexing of the arm and hand, and restlessness during the final 100 to 150 cycles of each session. The strip chart recorder that monitored successes also indicated changes in rhythm during this period. A few subjects demonstrated increased variation in response times toward the end of the sessions. Fatigue or boredom could not be eliminated as possible causes for these changes in behavior.

Subjects were instructed at the start of each session to minimize errors. The error rate per subject for 4 sessions ranged from 1.15 percent to 6.35 percent. Only one subject maintained an average error rate above 3 percent. The overall average error rate of 2.57 was considered very acceptable.

The second consideration involved the ability of the subjects to perceive the most probable integer (i.e. stimulus). In all cases the

subjects were able to correctly detect and report the actual most probable stimulus. Certain subjects were able to designate two or more most frequent stimuli when they occurred, and they could give their relative frequency accurately against the background of stimuli. Determination of the most likely stimulus could be done when that number represented only 30 percent of the total stimuli. (Table I, Tape 2) A threshold proportion was not determined.

Finally a best sequence of 36 characters from the stimulus stream of the fourth session was sought. Photographs from these 36 cycles would be used as data for hand motion calculations. Time data for the three practice sessions was used as a guide to the location of the best character string. The data from each subject for all three practice sessions was analyzed in 100 cycle increments. These data are summarized in Appendix C. The computer programs shown in the final section were used in determining such measures as sample mean, sample standard deviation, range, maximum and minimum response times, and in plotting learning curves over any desired subset of response time data. The best segment for data collection in the fourth session was judged to be between the 300th and 400th cycles. Cycles 300 through 336 were chosen from that 100 cycle segment.

The effects of learning on response time could not be determined because time considerations prevented the necessary replications of the task for any particular stimulus set. Examination of learning curves such as the one shown in Figure 4 suggest some slight learning effects during a given session. At the end of the practice sessions the subjects were assumed to have attained the fully learned state.

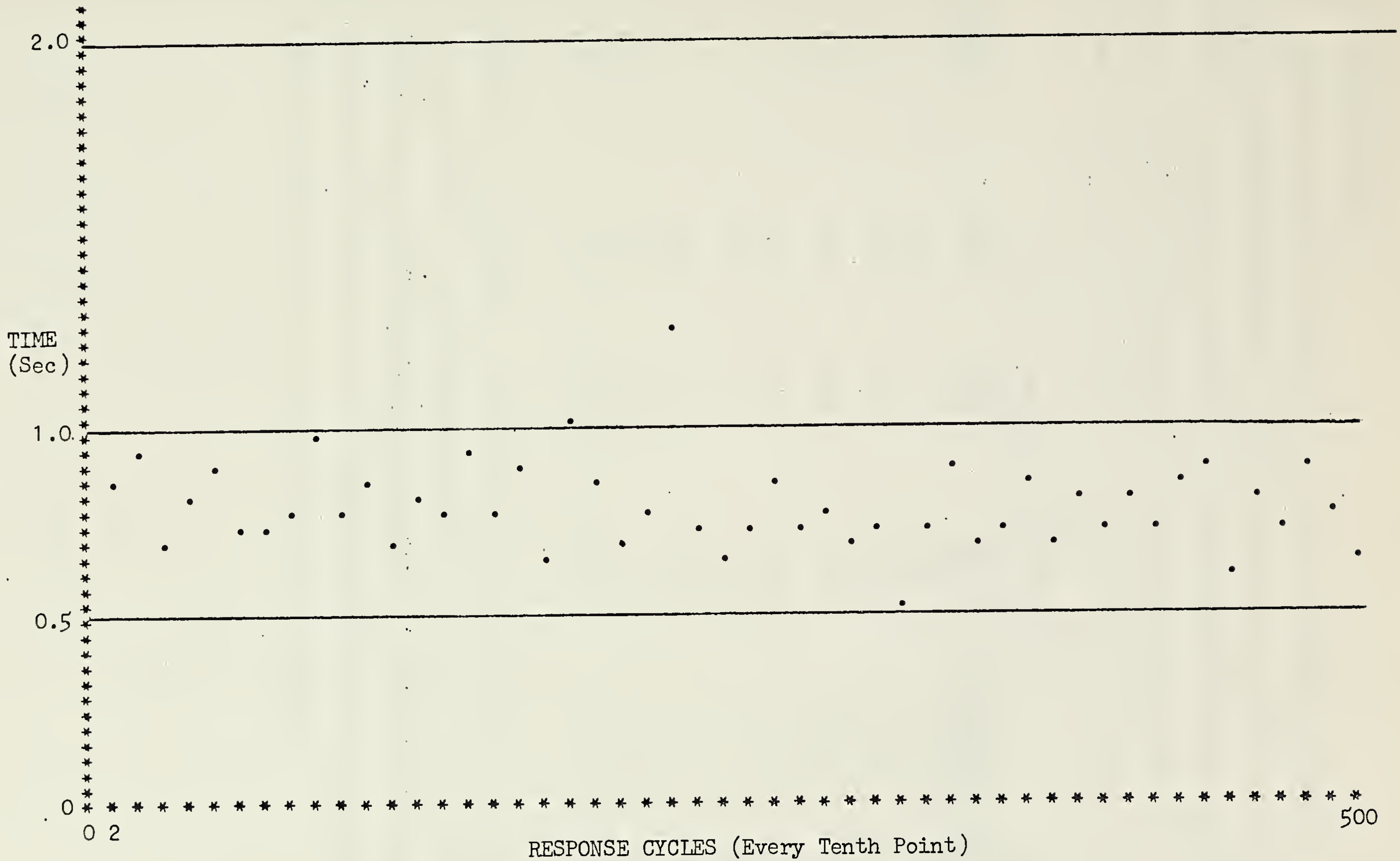


FIGURE 4. LEARNING CURVE OF RESPONSE TIME DATA

B. RESPONSE TIMES

Response time data gathered in the final session was analyzed to help in detecting strategies. A one-way analysis of variance was conducted using subjects as treatments and 400 response times per subject. Data was trimmed to minimize start up effects and obvious outliers. Summarized data is given in Table II. The resultant F statistic (37.153)

TABLE II. RESPONSE TIME SUMMARY

Subject	Cycles	Mean	σ	Minimum	Range
I	400	.703	.132	.349	.819
II	400	.768	.226	.219	1.489
III	400	.686	.178	.394	1.077
IV	400	.699	.160	.295	1.328
V	400	.747	.138	.471	.958
VI	400	.756	.182	.333	1.038
VII	400	.829	.123	.593	.749
VIII	400	.795	.150	.541	.846

indicated that performance varied greatly and between subject effects were significant. Multiple comparisons between pairs of these subjects resulted in the t statistics shown in Table III. These statistics indicate that the subjects could be grouped according to the distribution of their response times. The groups are shown in Table IV.

TABLE III. RESPONSE TIME t STATISTICS

Subject	I	II	III	IV	V	VI	VII	VIII
I		4.962	1.538	.386	4.631	4.732	14.0	9.2
II			5.714	4.960	1.590	.827	4.747	1.992
III				1.08	5.45	5.51	13.24	9.39
IV					4.528	4.691	12.264	8.73
V						.789	8.81	4.705
VI							6.636	3.305
VII								3.505
VIII								

TABLE IV. SUBJECT GROUPING

Group	Subjects
A.	I, III, IV
B.	II, V, VI
C.	VII
D.	VIII

C. HAND MOTION DISTANCE

Thirty-six photographs of each subject were taken during the best segment of the fourth session. Distance measurements were accurately read to .05 inches using a standard photographic enlarger. Photo interpretation techniques (see Appendix B) were used to match actual dimensions to projected dimensions. Each response distance was associated with its eliciting stimulus. Actual image specimens are shown in Figures 5.a. and 5.b.

The responses to a given stimulus number, across all subjects, were listed and ordered. Figure 6 shows the range of responses to each number, the mean response, one standard deviation each side of the mean, and the simulated distance described by the model for that stimulus. Differences between mean response distances and simulated quantities are listed in Table V.

TABLE V

DIFFERENCES BETWEEN SIMULATED AND MEAN RESPONSE DISTANCES BY ELICITING STIMULUS

Stimulus

1	2	3	4	5	6	7	8
1.28	-1.68	0.41	4.88	5.14	8.08	8.92	10.10

Inches

The mean response distance for each button by each subject was calculated. These statistics were used in a two-way analysis of variance to determine differences in performance between and among subjects and between and among stimuli. The resultant ANOVA Table is presented in Table VI.

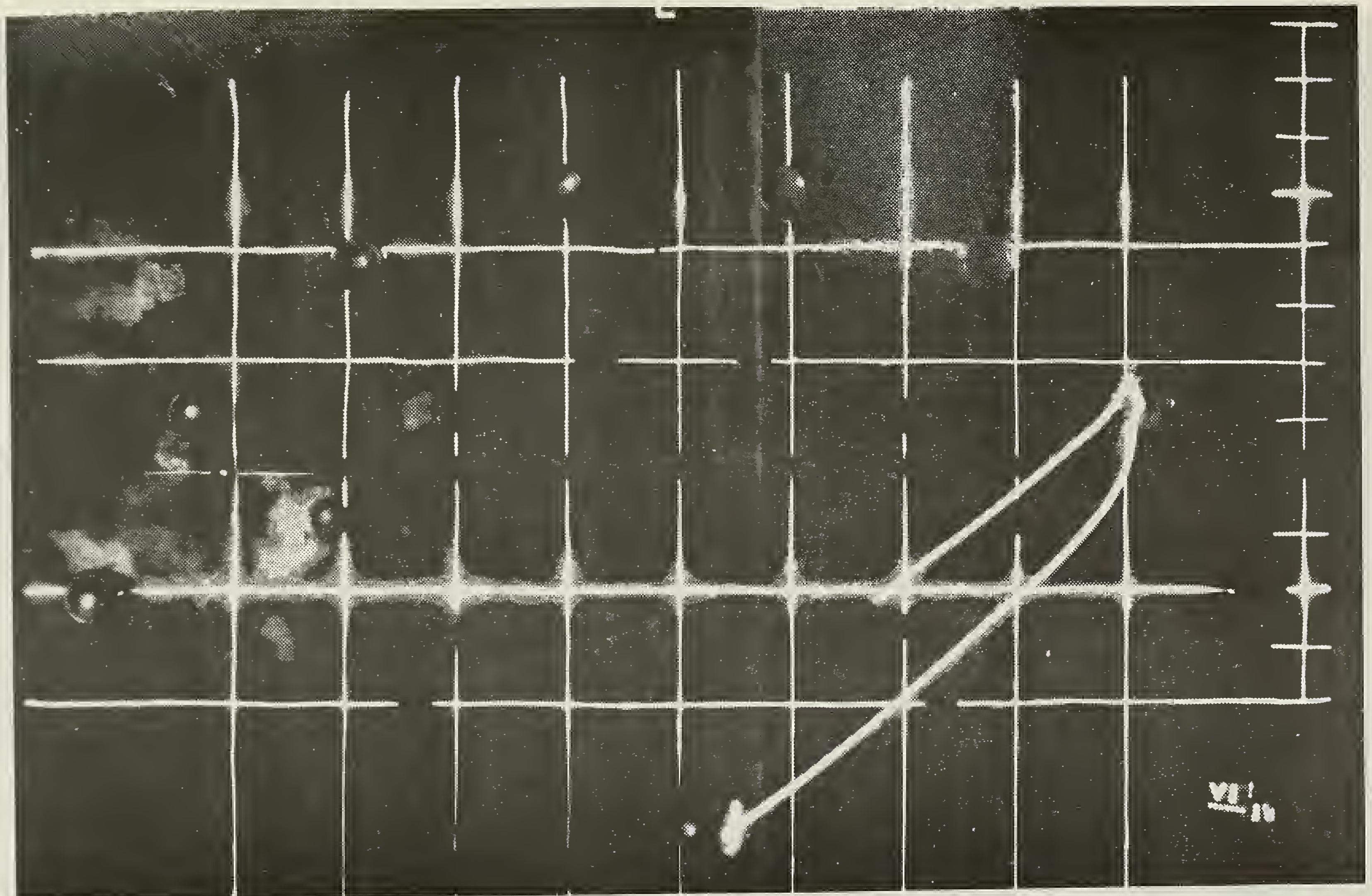


FIGURE 5.a. CYCLEGRAPH OF RESPONSE TO NUMBER 2

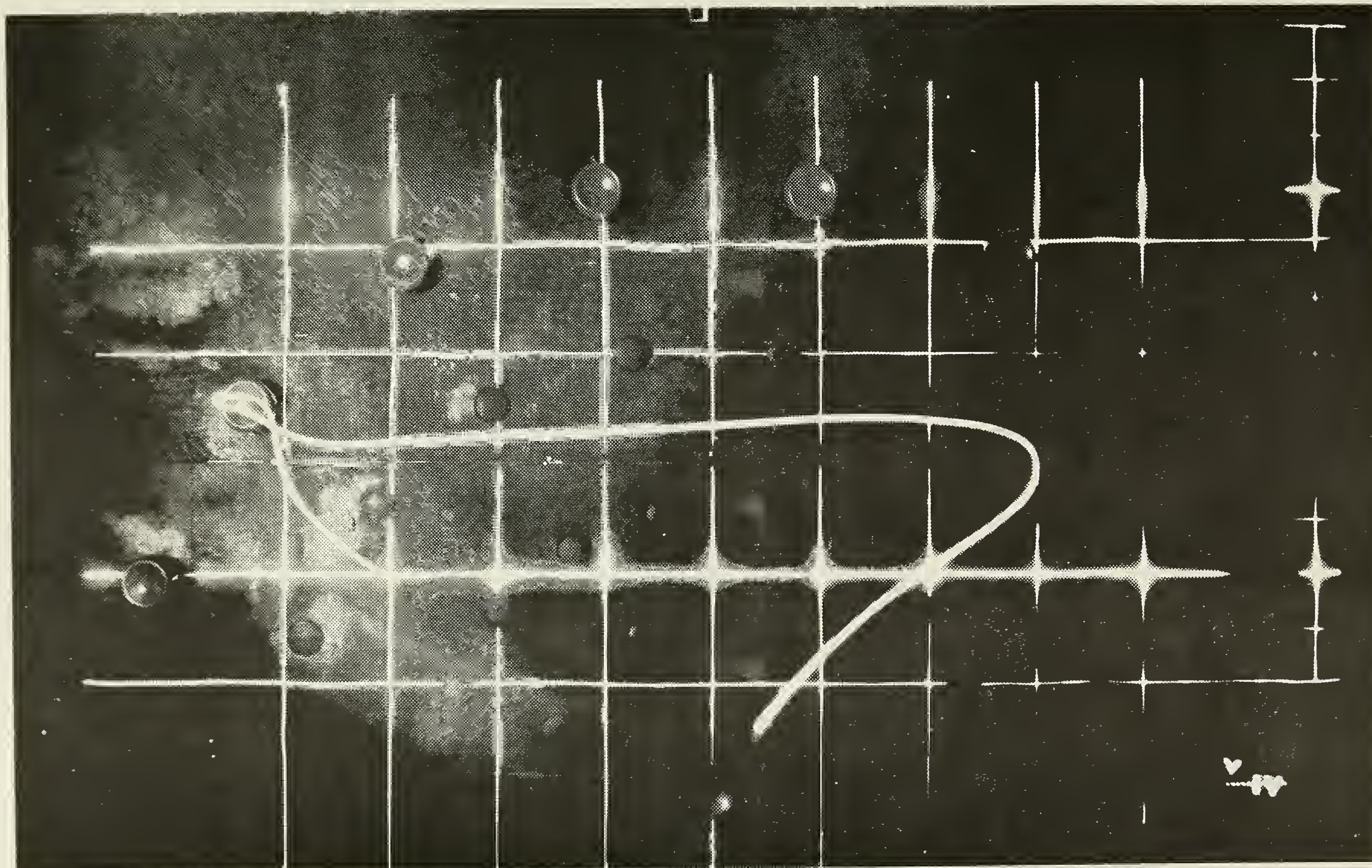


FIGURE 5.b. CYCLEGRAPH OF RESPONSE TO NUMBER 7

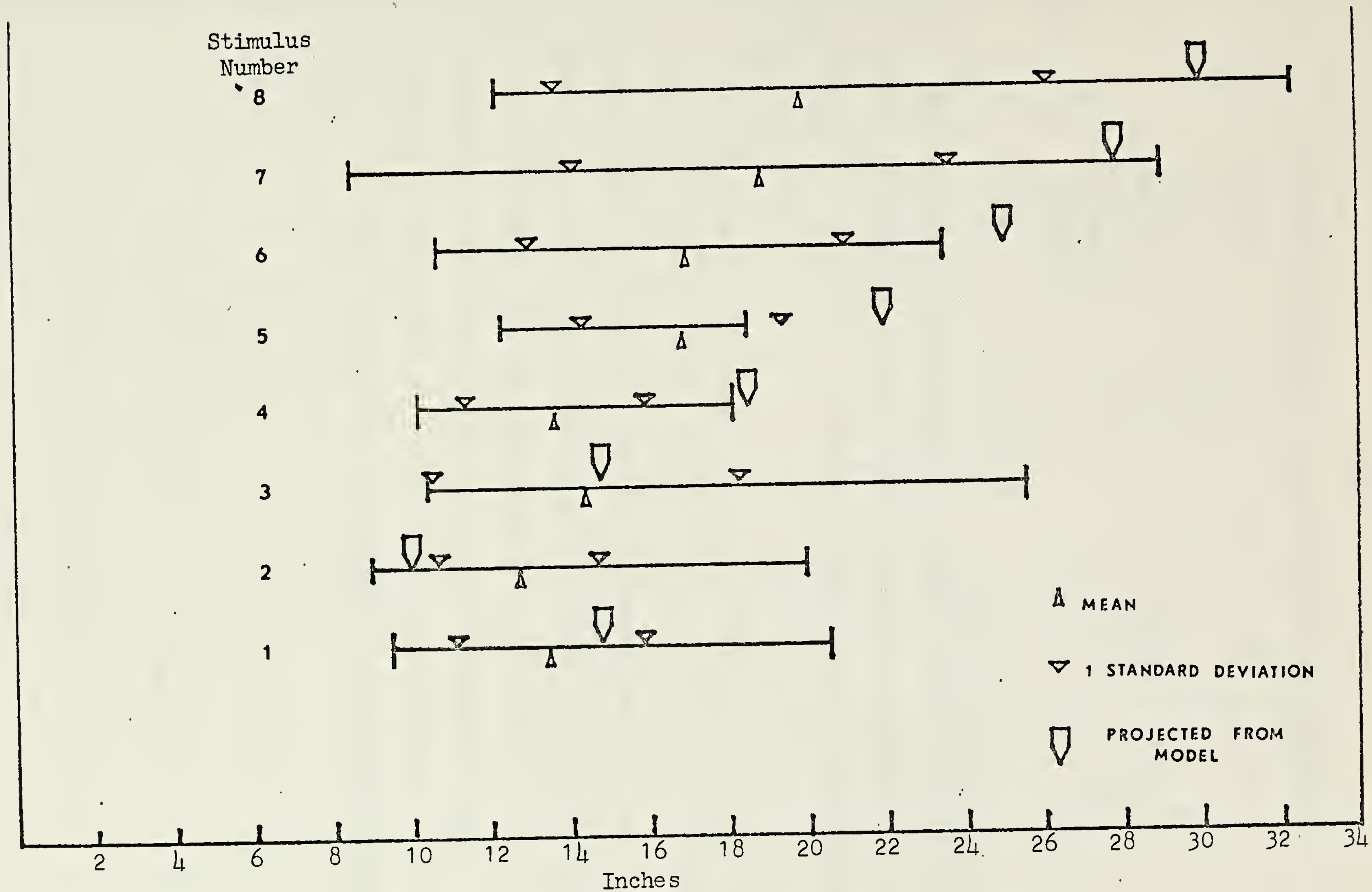


FIGURE 6. HAND MOTION DISTRIBUTION BY STIMULUS NUMBER

TABLE VI

ANALYSIS OF VARIANCE ON MEAN HAND MOTION DISTANCE

SOURCE	SS	DF	MS	F
TOTAL	1012.07	63		
SUBJECTS	271.63	7	38.804	5.962
TREATMENTS (Stimuli)	421.52	7	60.218	9.252
ERROR	318.918	49	6.508	

The F statistics are significant in both tests at all levels. Significant differences across stimuli were expected. Significant differences across subjects were indicated in correspondence with response time data.

Although the distributions of response distances to a particular stimulus were not known, the ordered data sets were found to fit normal distributions. An empirical cumulative distribution function was calculated and plotted versus the cumulative normal distribution function for the same data. The maximum allowable curve separation at the ith data point was calculated using the two-sided Kolmagorov-Smirnov "goodness of fit" statistic. This separation value was not exceeded at the .05 level in any data set. An example of curve fit is shown in Figure 7.

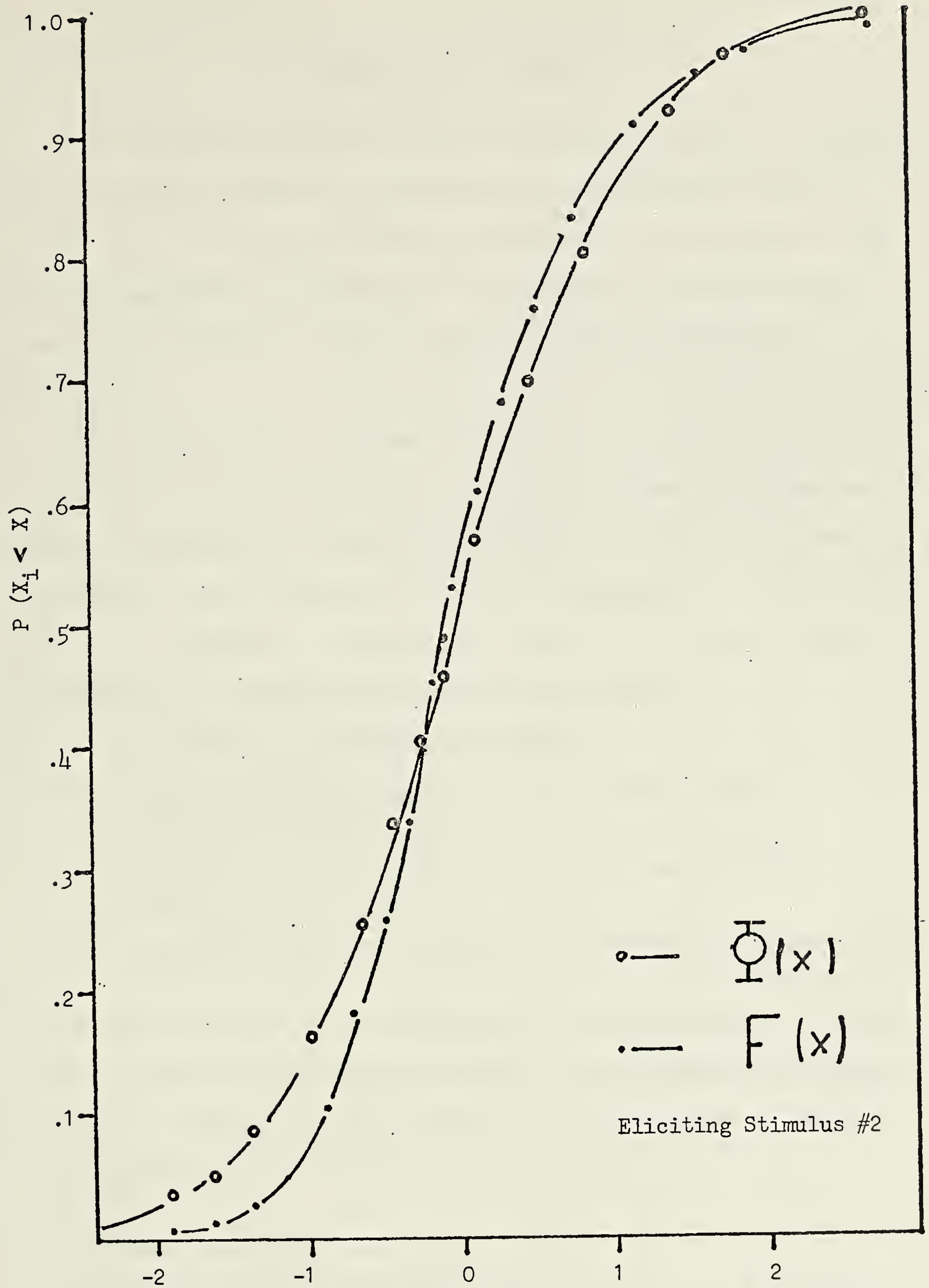


FIGURE 7. PLOT OF EMPIRICAL CUMULATIVE DISTRIBUTION AND STANDARD NORMAL DISTRIBUTION FOR HAND MOTION DATA.

V. DISCUSSION AND CONCLUSIONS

The investigation reported in this paper made full use of refined data gathering equipment in collecting and analyzing hand motion response data. Laboratory equipment functioned very reliably in a hands-off configuration. The results from the remotely controlled camera again demonstrated the value of the cyclegraph for accurate data collection.

The human subjects evidenced a high state of interest and competitiveness throughout the experiment. Aspects of human perception and decision processes which may have effected response data could not be quantified. However, observation of and conversation with the subjects hint at the existence of individual strategies for the task. Some motivational concepts expressed by the subjects were:

a) the desire for error-free performance.

b) a wish to perform the global minimum response time. (Subjects I, III, IV)

c) attempts at defeating the task through stimulus pattern recognition. (II, V, VI)

d) a parochial interest in measures of their own performance. (VII)

These varied concepts may have dictated the strategies employed on the task. Groupings are generally the same as those arrived at by multiple comparisons associated with response time data for the final session. (See Section IV.B.)

A. RESPONSE TIME DATA

The experimental results, while secondary in importance to hand motion were interesting.

1. Distributions of time data suggest that four different strategies were used by grouped subjects in the fully learned state.

2. Although subjective responses indicate minimal fatigue effects, observations of behavioral changes which might be the result of fatigue were made in the final cycles of a number of sessions.

B. HAND MOTION DISTANCE DATA

Hand motion seemed to be tied in some part to a subject's appraisal of the pattern of the stimulus characters. It appeared that a probability of occurrence was assigned to each of the stimuli after 50 to 100 cycles, and thereafter, only the 5 or 6 most likely were considered seriously. This form of coding would have had the effect of reducing the uncertainty of the stimulus set at the expense of a slightly higher error rate. Further, most subjects tried to minimize response times by predicting the next character to arrive based on the short subset of four to six characters immediately preceeding. In some cases it appeared that, using a reflex motion, the subject would depress the predicted button before he had recognized the actual stimulus being displayed. Comments uttered by the subjects after such an occurrence stressed the point that the machine had "tricked" them.

Although correct hand position was stressed before each session, the subjects tended to contact the buttons with various parts of their hand using a slapping motion. The base button was frequently hit with the heel of the hand while the response buttons were contacted with the fingers. These tendencies accounted for the hand motion distances that occurred which were less than the minimal radial distance of 11 inches. (See Table V and Figure 6).

Conclusions based on hand motion data are supported by Section IV.

1. Initial examination of motion distances showed that the model fairly accurately predicted hand motion when the required response was within 20-25 degrees of arc from the perceived most likely response. The mean responses were less than the distances described by the model for stimuli which were outside of those geometric limits.

2. The distribution of the distances moved in responding to the ith stimulus was assumed to be normal for all i. This assumption could not be rejected at the .05 percent level by non-parametric test procedures.

3. An analysis of variance of the mean responses to stimuli showed significant differences in response measures across subjects and across stimuli.

C. RECOMMENDATION FOR FURTHER STUDY

Extended research in hand motion is necessary to improve work surface design. Further work on this apparatus should provide suitable data for a number of investigations.

1. It is suggested that a base-line study be conducted in two areas:

   a. A threshold proportion for the perceived most likely stimulus should be established.

   b. An investigation of learning over four sessions using purely random stimulus sets would provide a data base for the determination of learning effects.

2. Individual analysis of 2,4,6, and 8 choice decision tasks to study voluntary elimination of stimuli should be attempted. More refined subjective methods incorporating motion pictures or television recordings may lend information about such strategies.

3. Scholes (1970) offered a model which ties movement time and reaction time to Fitt's (1954) index of difficulty and the required direction of motion for the task. It is suggested that investigation of this model be done using improved time collection abilities now available, and that cyclegraphic data be used for analysis of motion parameters. This would necessitate the modification of the button board to incorporate touch sense buttons so that an accurate index of difficulty can be established.

APPENDIX A: EQUIPMENT DESIGN AND SPECIFICATIONS

The laboratory equipment design involved the use of standard research machinery, a modern digital computer and advanced technology circuit elements. The major components were a button panel with stimulus, an integrated control circuit, a 35mm camera, and an on-line digital computer.

1. Button Panel

A control panel was simulated through construction of a push-button board. Button switches were placed in a symetrical, fan shaped layout with eight response buttons situated at a radius of eleven inches from the base position. The first button was placed on the radial twenty degrees above the horizontal base line. Successive buttons were spaced at 20 degree intervals along the radial arch. A ninth button, called the base or zero button was placed at lower center. See Figure 2. The numbering of the buttons was sequential running counterclockwise from the lower right position. They were not individually labeled. (The use of an unconventional numbering system increased the difficulty of the task). All buttons were wired through bounce suppression circuitry (Figure A.2, Drawing 4) to the control circuit.

The buttons were mounted in a plexiglas sheet .25 inches thick, which was fitted rigidly to a light table. The plexiglas was painted black and etched with a two inch grid pattern. A one foot line, etched in one inch graduations was also provided. The etching permitted the back-lighting to show through for photographic purposes.

The stimulus was provided by a seven segment readout, which was mounted on the plexiglas at top center of the board.

2. Control Circuit

Distribution of stimulus and response signals was accomplished through the use of a logic circuit constructed of integrated circuit chips. (Figures A1.a and A1.b). A pulse from the base button, or from any of the response buttons caused a paper tape reader to step. The binary code from the stimulus tape was read and subsequently decoded by two integrated chips of specialized design. The first chip displayed the binary code as an integer on the seven segment display. The second chip decoded the input into nine individual leads, each corresponding to an integer 0 through 8. These leaders were combined with leads from the like numbered push buttons through logic sub-circuits. Available logic combinations provided signals which performed the following five functions:

a. correct response indication

b. tape reader advance

c. camera control

d. cycle counting

e. response time signal distribution

3. Response Time Measurement

The response time for each cycle was defined as the time between depression of the base button and depression of any response button. Signals from the base button were delivered to channel 1 of the AME-8 A to D converter unit on the PDP-8 computer. The computer was instructed to interrogate channel 1 at 15 nanosecond intervals by the data collection program. Upon the receipt of a spiked pulse, the internal clock was started. It continued to count in millisecond units. The signal from any one of the response buttons was delivered

to channel 2 of the converter. When a spike pulse was received, the clock was stopped and the value of the unit counter transferred to memory under a number label corresponding to the completed cycle. Interrogation was then transferred back to channel 1. After 500 counted cycles, the computer stopped interrogating and produced the data array on punched tape or typed listing. The data collection program is listed in the Computer Programs section.

4. Motion Photography

Collection of hand motion data was accomplished through time exposure photography. A Topkon Super-D 35mm camera with automatic film advance was positioned above the work surface at a distance of 28.5 inches. The field of view of the camera encompassed the board and the digital light. Slow speed black and white film was used to capture a single hand motion per frame. A small light was attached to the back of the subject's hand. Electrical connectors on the camera were attached to the control circuit through a small interfacing and sequencing circuit. A schematic of this interface is provided in Figure A2, Drawing 1.

A pulse from the base button opened the lens on the camera. It remained open until a pulse from any response button was received. The second pulse closed the lens and the film was advanced by the motor wind. The time exposure mode was selected because the response times varied across a number of the available fixed exposure durations. Lighting conditions and f-stop settings were experimentally determined so that exposures contained the grid depiction and the light streak, but had suppressed images of the hand. Figures 7.a and 7.b are examples of the results.

5. <u>Success Determination</u>

Logic circuitry as shown in Figure A1.a. provided a spike pulse whenever the response matched the stimulus being presented. These were recorded on a standard two channel Brush recorder at 1 mm/sec. Total successes after each session were subtracted from total cycles in calculating total errors.

6. <u>Equipment Specifications</u>

Camera:

Beseler Topkon Super-D 35 mm SLR still camera

Motor drive film advance with battery pack

58 mm f 1.4 Topcor automatic lens

Buttons:

Grayhill push button two position (n.o.) switches

Tape Reader:

OHR-tronics Model 166 single direction 8 channel paper tape reader

Max Frequency: 30 characters/Sec

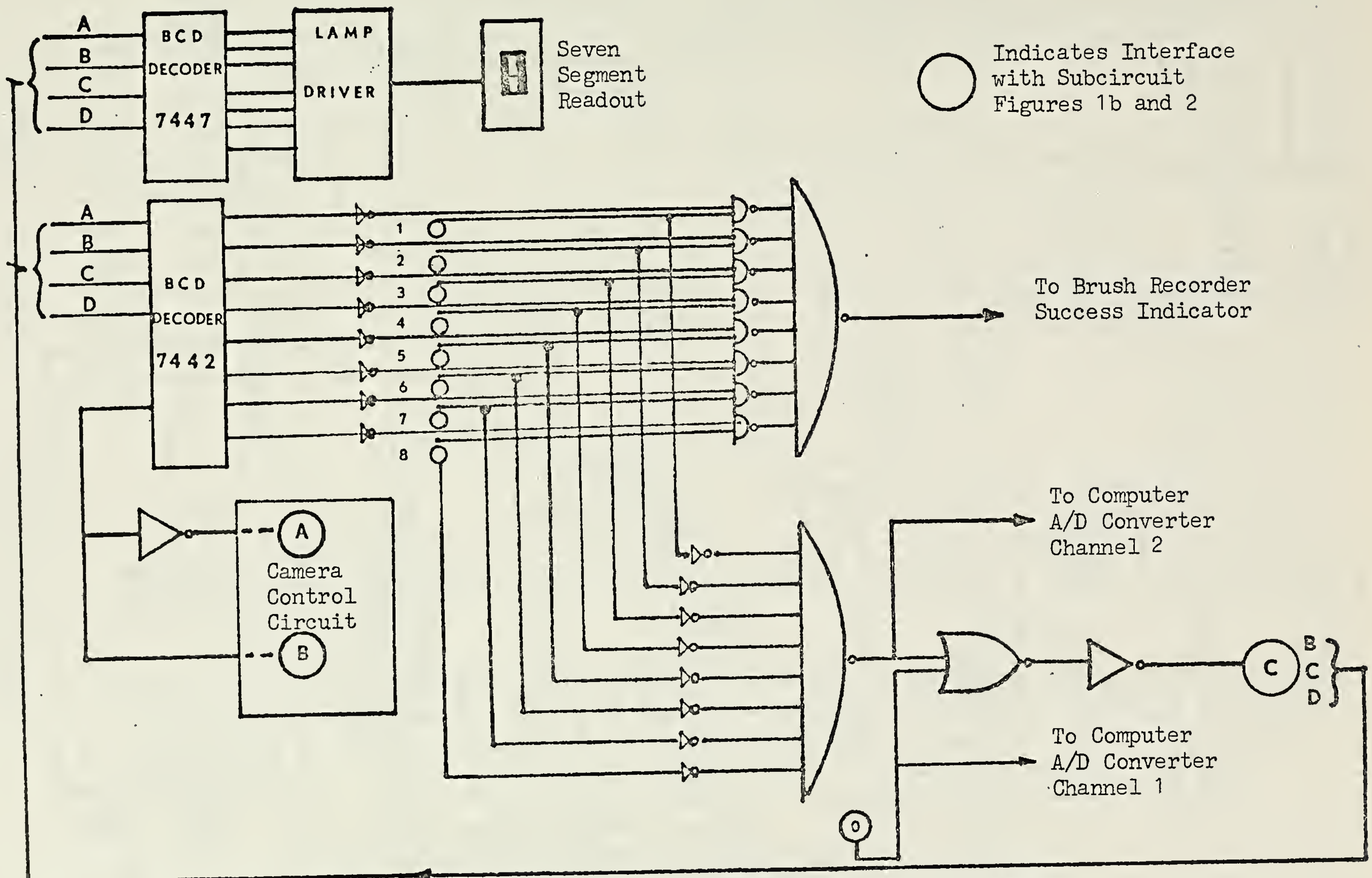
Integrated Circuit Chips:

Signetics or Fairchild 5 volt digital TTL

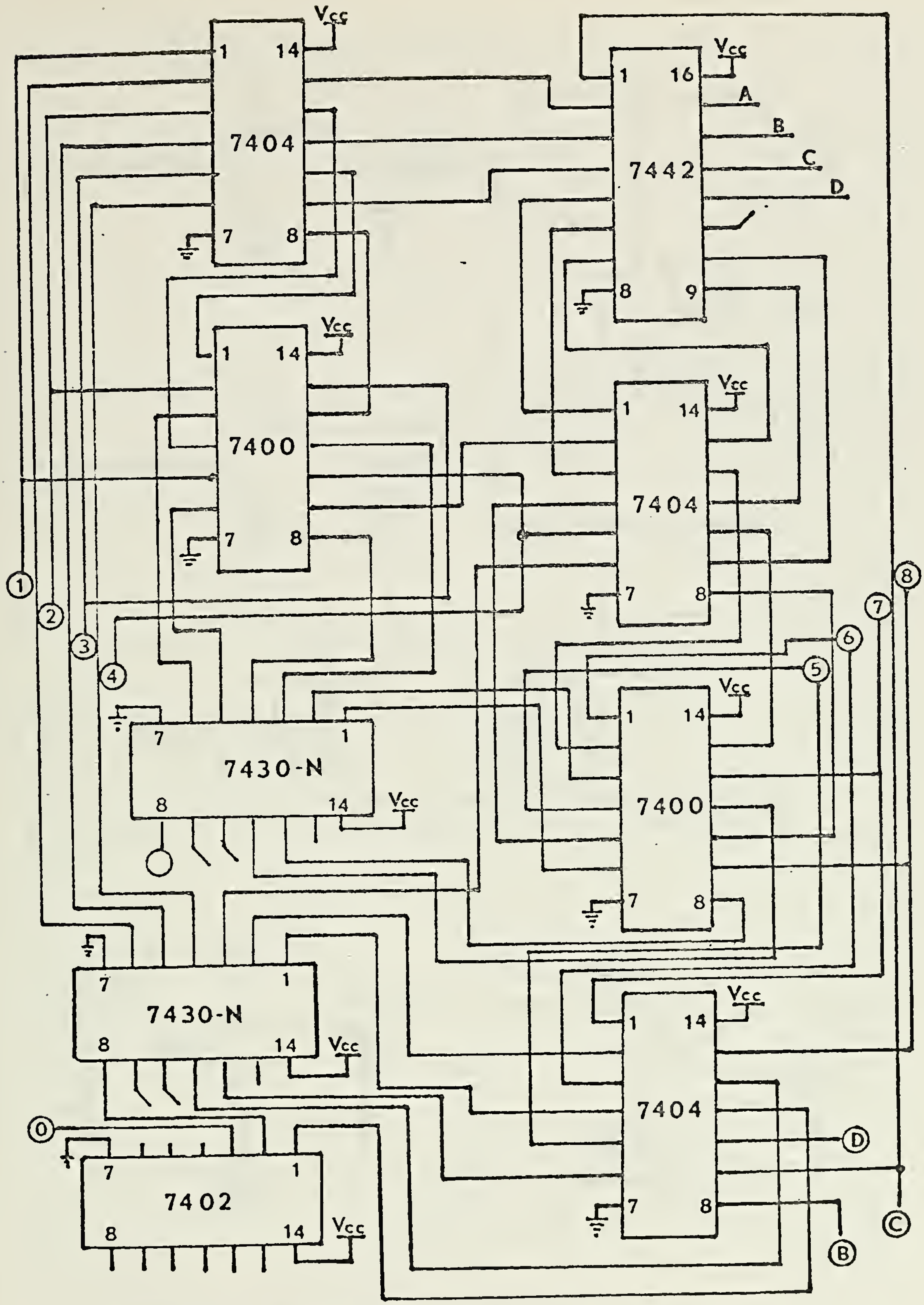
Chip Number	Quantity	Description
7442	1	BCD Decoder
7447	1	Lamp Driver/Decoder
7400	2	Quad 2 input Positive Nand Gate
7404	3	Hex Inverter
7403N	2	8 Input Positive Nand Gate

7 Segment Digital Display: Alco Mosaic Readout 3-5 Volts

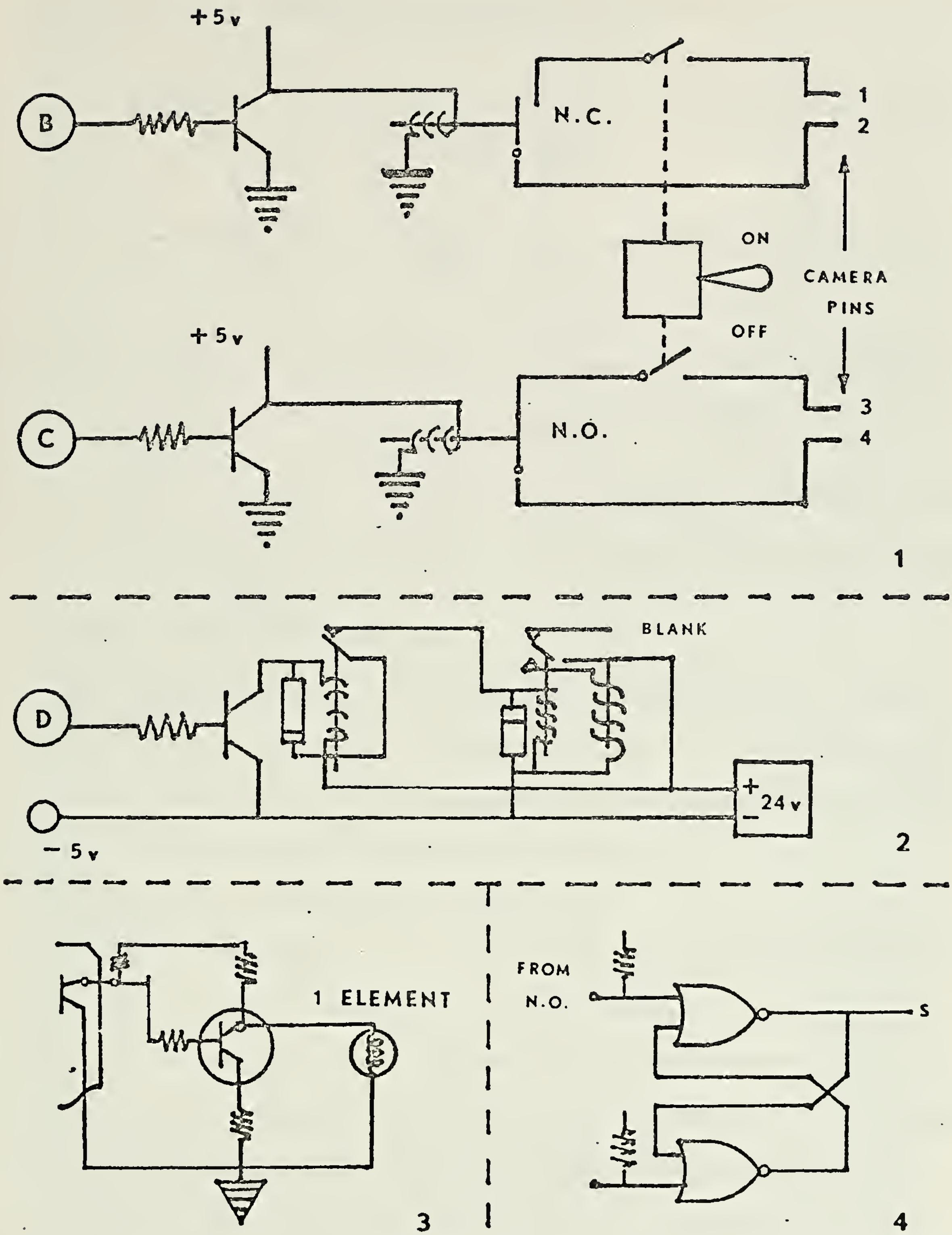
24 Volt Power Supply	1
5 Volt Power Supply	1



APPENDIX A. FIGURE A1.a. CONTROL CIRCUIT LOGIC DIAGRAM



APPENDIX A. FIGURE A1.b. CONTROL CIRCUIT SCHEMATIC



APPENDIX A. FIGURE A2. PERIPHERAL SYSTEM SCHEMATIC

APPENDIX B. CYCLEGRAPH INTERPRETATION

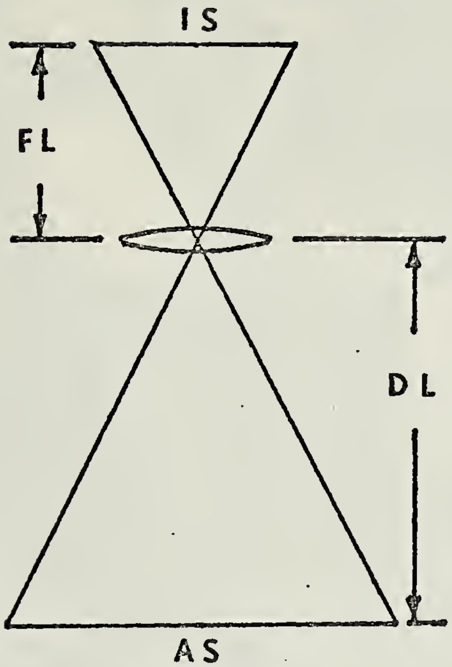


FIGURE B1
PHOTO INTERPRETATION GEOMETRY

FL = Focal Length

Distance from focal plane to lens center

IS = Image Size on film at focal plane

DL = Distance from lens center to object or projection

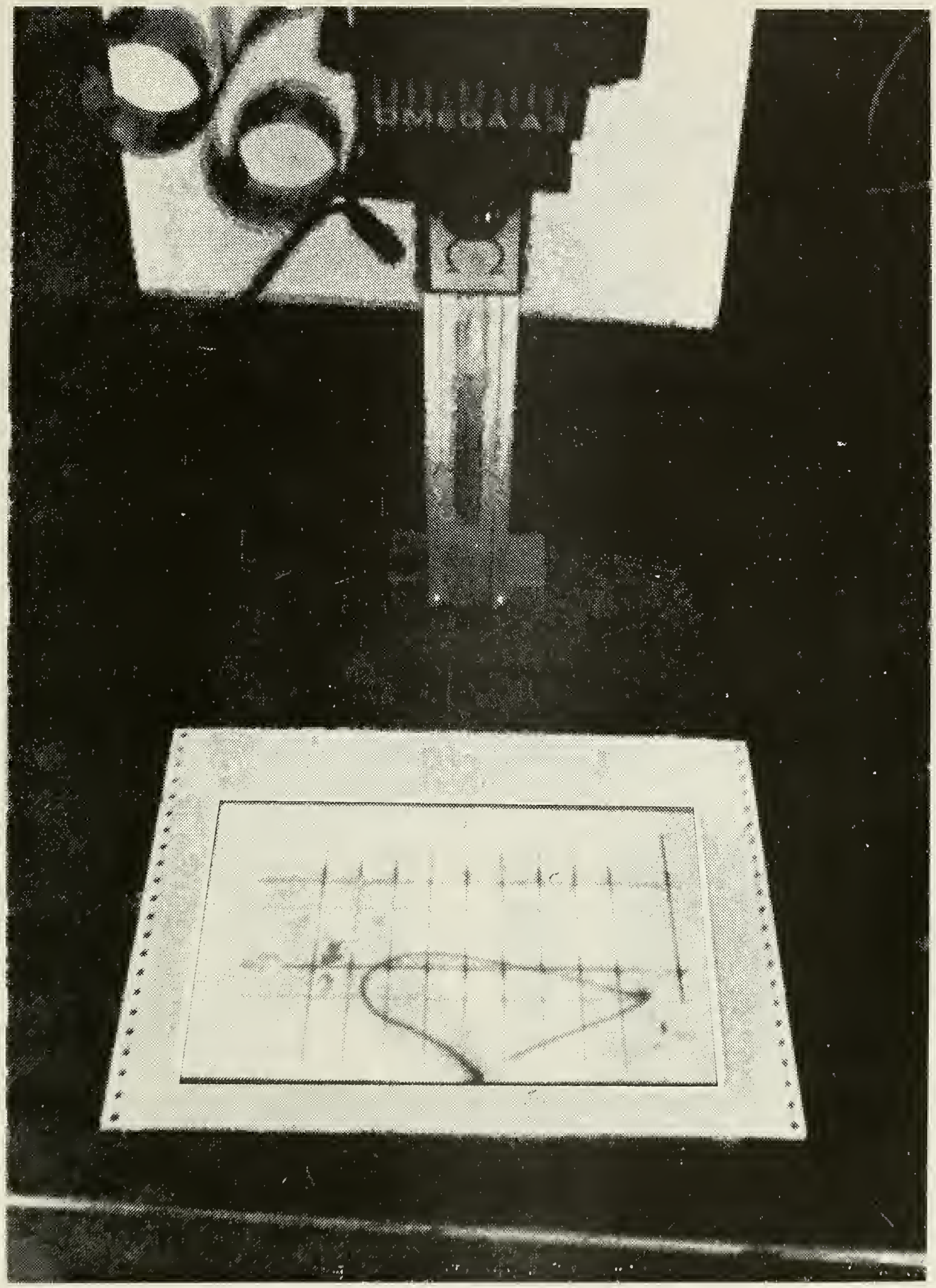
AS = Actual Size of object at distance DL or length of travel at distance DL

$\frac{IS}{FL} = \frac{AS}{DL}$ is the geometric relationship. If the blow-up is larger than the size of the original negative by a multiplication factor the effective mathematical adjustment is to multiply focal length (FL) by that same factor.

For this study representative lengths were:

FL = 1.378 inches	AS = 12 inches for reference line
IS = 28 mm x 35 mm	DL = 28.5 inches

Actual negatives were enlarged 8 times for reading purposes. A one inch grid segment on the button board was represented by a length of .386 inches on this blow-up. The image of the scribed one foot reference line was matched exactly to a 4.63 inch line on the projection surface prior to the reading of each negative. See Figure 2 this Appendix.



APPENDIX B. FIGURE B2. ENLARGER WITH PROJECTION

APPENDIX C. TIME DATA SUMMARY

Response Time Data Summary for Three Practice Sessions

Subject	Cycles	Mean	σ	Minimum
First Practice Session				
I	496	1.063	.19862	.730
II	497	1.0607	.2135	.72
III	498	.8742	.1849	.593
IV	497	.99436	.1555	.708
V	500	.949	.1678	.618
VI	495	1.017	.1719	.735
VII	500	1.060	.1579	.826
VIII	487	1.087	.2338	.712
Second Practice Session				
I	499	.8415	.0971	.657
II	500	.8359	.1212	.581
III	499	.7623	.1201	.542
IV	500	.798	.095	.574
V	499	.869	.1392	.624
VI	500	.8428	.1421	.535
VII	500	.865	.1216	.696
VIII	493	.912	.173	.581
Third Practice Session				
I	500	.7037	.1523	.272
II	487	.7237	.2164	.285
III	492	.7047	.1422	.261
IV	497	.7421	.1654	.289
V	498	.7323	.1495	.388
VI	488	.7335	.2015	.269
VII	499	.7351	.1512	.293
VIII	496	.7944	.1475	.565

```
1 REM -PROGRAM TO SIMULATE THE ACTIONS OF A MAN AT A CONTROL
2 REM - PANEL UNDER STIMULI WITH DIFFERING PROBABILITIES OF
3 REM - OCCURRENCE. ANSWERS ARE LISTED AS "SMD", THE SINGLE
4 REM - MOTION DISTANCE, AND "B", THE TOTAL DISTANCE FOR "N"
5 REM - TRIALS.
6 DIM P(3),S(3),D(8,8)
7 PRINT "TYPE IN P1 THRU P3 ON SUCCESSIVE LINES."
10 FOR I=1 TO 3
12 INPUT P(I)
15 NEXT I
16 PRINT "TYPE IN TOTAL INTEGERS DESIRED."
17 INPUT T
18 FOR V=Ø TO 8
19 FOR W=Ø TO 8
20 READ D(V,W)
21 NEXT W
22 NEXT V
23 PRINT "TYPE IN THE MOST LIKELY STIMULUS NUMBER."
24 INPUT Z
25 N=10\M=Ø\B=Ø
28 PRINT "INT","SMD","TRIAL NO.","TOTAL DISTANCE"
135 LET M=INT(3*RND(Ø)+1)
136 S(M)=S(M)+1
145 IF S(M)/N<P(M)GO TO 175
165 S(M)=S(M)-1
170 GO TO 135
175 N=N+1
176 PTP\PRINT Ø\PRINT M
177 TTY OUT
180 A=11+D(Z,M)\B=B+A
191 PRINT M,A,N-10,B
192 IF N-10<TGO TO 135
195 PRINT "THE PROPORTION OF THE INTEGERS ARE:"
198 N=N-10
200 FOR I=1 TO 3
205 PRINT S(I)/N
206 NEXT I
210 DATA Ø,Ø,Ø,Ø,Ø,Ø,Ø,Ø,Ø
211 DATA Ø,Ø,3.32,7.524,11,14.141,16.353,19.Ø53,2Ø.673
212 DATA Ø,3.32,Ø,3.32,7.524,11,14.141,16.353,19.Ø53
213 DATA Ø,7.524,3.32,Ø,3.32,7.524,11,14.141,16.353
214 DATA Ø,11,7.524,3.32,Ø,3.32,7.524,11,14.141
215 DATA Ø,14.141,11,7.524,3.32,Ø,3.32,7.524,11
216 DATA Ø,16.353,14.141,11,7.524,3.32,Ø,3.32,7.524
217 DATA Ø,19.Ø53,16.353,14.141,11,7.524,3.32,Ø,3.32
218 DATA Ø,2Ø.673,19.Ø53,16.353,14.141,11,7.524,3.32,Ø
220 END
```

COMPUTER PROGRAMS

The preceding program in BASIC was written and executed on the PDP-8 computer. The program requested the desired proportions of the integers that are to appear on the tape. It then called a subroutine which generated a random number between zero and one. This random number was converted to a random variate (I) between 1 and 8 inclusive. The counter associated with that variate, S(I), was incremented and the proportion S(I)/n, where n was the total punched integers to date, was checked against the desired proportions. The number was rejected if that proportion was too large and all counters were decremented.

An accepted number was punched on the paper tape followed by a zero, both in ASCII code. The accepted number was also used in the next part of the program. The later section was a simulation routine which used the theoretical model to calculate the individual motion distances and the cumulative distance moved for the exact character string being punched on the tape.

The random number generator used to initiate the program was based on 12 bit word size and did not require a seed. The resultant number string had a period of 1024 numbers [Ref. 3]. Character strings were verified for randomness over 100 character segments and across the completed string.

Each tape was punched with 600 integers in ASCII code. The ASCII tapes were converted to binary code which could be read by the tape reader through use of the following machine language program on the CDC - 160 computer.

STIMULUS TAPE CONVERSION PROGRAM

ASCII to BCD numbers 1/9/73

```
0000  7500
0001  4102
0002  7203          read 5 frames
0003  0065
0004  6102
0005  0060
0006  2063
0007  0217          save lower 4 bits of number

0010  4070
0011  7500
0012  4104
0013  7303
0014  0071
0015  6102          punch lower 4 bits
0016  0070
0017  7101

0020  0000          return to start
```

TIME DATA COLLECTION PROGRAM

```
1 REM - THIS PROGRAM CONTROLS CHANNELS 1 AND 2 OF THE AME-R
2 REM -MULTIPLEXER. THE TIME DIFFERENCE BETWEEN THE ARRIVAL
3 REM -OF TWO SIGNALS CAN BE MEASURED TO .001 SEC. IF
4 REM -THE FIRST TO ARRIVE IS ON CHANNEL 1, THE SECOND AT
5 REM - 2. REQUIRED MINIMUM MAGNITUDE IS .1 VOLT.
10 DIM A(500)
20 T=0\I=1
25 PRINT "TURN THE PAPER TAPE PUNCH ON, PLEASE."
30 PRINT "INPUT LIMIT OF NUMBER OF TRIALS TO BE RECORDED."
40 INPUT L
100 IF ADC(1)<.1GO TO 100
150 SET RATE 3,1
200 IF ADC(2)<.4GO TO 200
210 LET A(I)=TIM(0)
220 LET I=I+1
222 IF I<L+1GO TO 100
225 PRINT "WANT A HARD COPY NOW? TYPE 1=YES,2=NO."
226 INPUT J\IF J=2GO TO 260
235 PRINT "OUTPUT OF ";L;"TIME INTERVALS"
238 PRINT "TRIAL #","RESPONSE TIME"
240 FOR K=1 TO L
250 PRINT K,A(K)/1000
255 T=T+A(K)
258 NEXT K
260 RESTORE
261 PTP
262 FOR N=1 TO L
263 PRINT A(N)/1000\T=T+A(N)
264 NEXT N
265 T=T/L
266 TTY OUT
267 PRINT "THE AVERAGE RESPONSE TIME IS"T/1000"SECONDS."
270 STOP
280 END
```

GENERAL DATA ANALYSIS PROGRAM

```
10 DIM A(500)
15 PRINT " INPUT THE NUMBER OF DATA POINTS YOU WILL USE."
20 PRINT " MAX AVAILABLE IS 500."
25 INPUT L\S=0\S2=0\C=0\N=0\W=0\P=0
28 M2=100\M3=0
30 PRINT "INDICATE DATA INPUT MODE, 1=PTR,2=TTY"
40 INPUT M
50 IF M=2GO TO 110
60 PRINT "POSITION TAPE AND TURN ON THE PTR"
65 PRINT " WHEN READY TYPE IN A 1."
70 INPUT E
75 PTR
80 FOR I=1 TO L
85 INPUT A(I)
86 IF A(I)>5GO TO 90
87 IF A(I)<.01GO TO 90
88 IF A(I)>M3 THEN M3=A(I)\IF A(I)<M2 THEN M2=A(I)
90 NEXT I
95 TTY OUT\TTY IN
100 GO TO 140
110 PRINT "TYPE IN DATA POINTS AS INDICATED."
115 PRINT "POINT"
120 FOR I=1 TO L
125 PRINT I
130 INPUT A(I)
132 IF A(I)>M3 THEN M3=A(I)\IF A(I)<M2 THEN M2=A(I)
135 NEXT I
140 PRINT "TYPE IN THE UPPER BOUND ON DATA VALUES"
145 INPUT Z
147 PRINT "SET FLAG-EARLY RUN=1,LAST RUN=2."
148 INPUT F2
155 PRINT "TYPE STARTING PT. NO.,THEN STOPPING PT. NO."
156 INPUT Q\INPUT L\F=L
158 FOR K=Q TO F
159 IF A(K)<ZGO TO 180 \IF F2=1GO TO 164
163 LET F=L-P\A(K)=A(F)\A(F)=0\K=K-1
164 P=P+1
170 GO TO 190
180 IF A(K)<.01GO TO 164 \C=C+A(K)
185 S2=S2+(A(K))↑2
190 NEXT K
191 N=L-Q+1-P\L=N
195 D=SQR((S2-((C↑2)/N))/(N-1))
200 E=D/SQR(N)
```

```
235 PRINT N,C/N,D,E,P\C=0\D=0\E=0\P=0
240 PRINT "WANT NEXT GROUP=4,RANGE=3,NEW DATA=2 0R STOP=1?"
245 INPUT S
250 IF S<2GO TO 400
255 IF S<3GO TO 15
260 IF S<4GO TO 300
262 N=0\C=0\S2=0\P=0\D=0\E=0
265 GO TO 147
300 RESTORE
302 IF F2=1GO TO 380
314 IF K+Y-1>L-1GO TO 316
315 C=K+Y-1\GO TO 318
316 C=L-1
318 FOR M=K TO C
320 IF A(M)<A(M+1)GO TO 335
325 W=A(M)\A(M)=A(M+1)\A(M+1)=W
335 NEXT M
338 NEXT E
340 NEXT K
360 NEXT I
361 IF ((L-Q+1)/2)>INT((L-Q+1)/2)GO TO 364
362 M1=(A((L-Q+1)/2)+A((L-Q+3)/2))/2
363 GO TO 365
364 M1=A(INT((L-Q+1)/2)+1)
365 PRINT "MEDIAN="M1,"RANGE="(A(L)-A(Q))
375 PRINT "MINIMUM="A(Q),"MAXIMUM="A(L)
378 GO TO 240
380 PRINT "MIN="M2,"MAX="M3,"RANGE="M3-M2
398 GO TO 240
400 END
```

PLOTTING PROGRAM FOR PDP8 SCOPE
OR TELETYPE OUTPUT

```
1 DIM A(500),Z(100)\USE Z
2 PTR
3 FOR I=1 TO 500\INPUT A(I)\NEXT I
4 PRINT " TURN ON THE SCOPE FOR WARM-UP."
6 TTY OUT
7 PRINT "INPUT THE NO. OF POINTS YOU WILL EXAMINE."
8 INPUT L
10 PRINT "TYPE IN THE STEP SIZE"
12 INPUT M
13 PRINT "WHAT DATA POINT DO YOU WISH TO START WITH ?"
14 INPUT O
15 PRINT "NOW LOOK AT THE SCOPE AND CENTER THE DOT."
16 PRINT "WHEN FINISHED TYPE A 1."
17 CLEAR
20 PLOT .55,.5
25 FOR I=1 TO 100\DELAY\NEXT I
30 INPUT U
60 FOR I=O TO L STEP M
85 E=(A(I)-.5)/2
88 F=((I-O)/(L-O))*1.1
89 PLOT F,E
90 FOR N=1 TO 10
95 DELAY
100 NEXT N
105 NEXT I
110 PRINT "WANT A HARD COPY? TYPE 1-YES, 2-NO."
112 INPUT K
114 IF K=1GO TO 120
115 GO TO 133
120 GOSUB 171
133 PRINT "WANT TO STOP NOW? TYPE 1-YES, 2-NO."
134 INPUT P
140 IF P=1GO TO 160
145 RESTORE
148 TTY OUT
149 CLEAR
150 GO TO 6
160 END
171 PRINT
172 PRINT
173 PRINT
174 PRINT
175 PRINT "**********************************************"
180 FOR K=O TO L STEP M
185 E=((A(K)-.5)/2)*72
190 IF E>=INT(E)+.5GO TO 205
```

```
195 G=INT(E)
200 GO TO 210
205 G=INT(E+1)
210 PRINT "*";TAB(G);"."
220 E=0\G=0
229 NEXT K
230 PRINT \PRINT \PRINT
240 RETURN
250 END
```

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. ABSTRACT

An experimental investigation was conducted to examine a descriptive model for hand motion under discrete uncertainty of the stimulus set. The design and implementation of an automatic, on-line, data collection device using cyclegraphic motion collection methods is described. Eight subjects were exposed to 2.2 to 3 bits of choice uncertainty. Response times, error rates, and hand motion distances were collected and analyzed. Hand motion distances were compared to straight line distances used in control panel design. Further investigation indicated that the distributions of hand motion distances, for any stimulus, fit normal curves, and that variations in subject performance were significant. Perceptual aspects of the task and operator strategies are discussed. Further study is suggested.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Man-Machine Interface						
Manual-Decision Task						

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Thesis
S7147 Stewart
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